IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

SPECIFICATION

ELECTROCHEMICAL MICROSENSOR PACKAGE

BACKGROUND OF THE INVENTION

This invention relates to electrochemical microsensors and particularly to structures or packages which may be advantageously utilized for the manufacture of a wide variety of miniature or "micro" sensors. This invention also relates to methods for the manufacture of such microsensors and packages therefor.

Electrochemical microsensors have a wide range of existing and potential uses in various arts for chemical detection and measurement, especially in biochemical applications such as in medicine. In order to succeed in the point of care market, the biosensor systems must meet their application needs. Planar electrochemical sensors with microelectronic production techniques are known as an elegant approach to meet these requirements. Due to the batch processing and high precision of microelectronic techniques, the miniaturized planar sensors have major advantages including small dimension, low cost per sensor, high reproducibility and the possibility of smart sensor realizations.

In the past few years, a number of micro-fabricated sensors have been designed and developed by microelectronic techniques as exemplified in U.S. Patent 4,874,500. These sensors are usually fabricated by opening wells in a silicon chip using IC technologies and filling the wells with sensing chemicals. The bottoms of the wells are typically coated with silver and the surface of the silver converted to silver chloride. Then a hydrogel containing a known concentration of chloride ions is

placed into the well on top of the silver chloride, creating a known electrochemical potential between the hydrogel and the silver chloride electrode. The well is then covered with a membrane that has in it chemical that effects the attraction of the target ion. An electrochemical potential is developed between the silver and the unknown liquid through the hydrogel that depends on the relative concentration of the target ion between the membrane and the target liquid, which is determined by the concentration of the target ion in the target liquid. The are usable for detecting various ions as well as gases. However, in these cases, silicon is only a substrate and does not play any role in the sensing mechanism itself. Using silicon to make the wells is expensive. Multiple sensors on the same chip are incompatible requiring wide separation which in turn, causes low yields and large chip sizes. Low yields and large chip sizes combined with expensive fabrication processes causes the finished product to be costly. Our alternative avoids these problems and also uses inexpensive materials and processes for an order of magnitude cost advantage. There also exist some problems concerning the final package of the sensors because a chemical sensor on an insulating substrate is almost always easier to package than on a piece of silicon with conductive edges in need of insulation. Moreover, many chemical sensor materials are incompatible with IC processing; therefore the very point of using silicon is forfeit for many chemical sensors.

For connection with associated electronics, such micro-fabricated sensors have relied upon a conductor extending from the sensor well that is on the same surface as the opening in the sensor well. Placing such pins so they made good electrical contact while at the same time not damaging the sensor is difficult. Alternatively, wire bonding is used to make electrical connection to the conductor on the sensor. The completed assembly is delicate and easily broken. Also, since the hydrogel in the microsensors are vulnerable to elevated temperatures, soldered connections are not a viable option. A more robust construction would be to bring the electrode connection out of the sensor well to the side of the sensor opposite from the opening in the sensor well itself. Such a construction is difficult to achieve using silicon fabrication techniques.

Pressure type electrical contact buttons are described in U.S. Patents 5,364,277, 5,197,184 and 5,207,887 which are formed integrally with an electrical trace fixed on a substrate and which project through and outwardly of the substrate for make contact by pressing against another contact element. However, these contacts are for employment as terminal connections for wire cable terminations and there is no suggestion that these contacts could have any utility for electrochemical microsensors or how they might be adapted to be employed therewith

Lately, flexible polyimide film (Kapton) has been used as a substrate in micro-fabricated planar sensor arrays. Photolithography and sputtering technologies are used in the fabrication of the sensor arrays. These sensor arrays have shown good analytical properties for in-vivo measurements and have solved the problems with respect to membrane optimization, adhesion of membrane to its substrate, etc., but the sputtering process causes the fabrication of sensors to be expensive and time consuming

SUMMARY OF THE INVENTION

This invention relates to a new design and fabrication process for miniaturized electrochemical sensors and packages therefor. In this design, miniaturized electrochemical sensors, may be fabricated on sheets of a non-silicon material substrate by a batch, modular-manufacturing methodology.

Microsensor packages produced in accordance with this invention may be charged with electrolytic media or analytes appropriate to the desired sensor or electrode end use. The individual devices may then be separated from the sheet and then integrated into appropriate combinations or systems, such as multiple analyte sensor arrays, using pick and place technology. By fabricating identical miniaturized devices on a single large sheet of substrate the yield substantially increases over conventional substrates.

The microsensor packages of this invention comprise a laminated substrate of a first and a second non-conductive layer having a conductive trace that extends over an area of their interface. A sensing electrode is also located at the interface adjacent

to and in electrical contact with the conductive trace. A sensor well is provided in the first conductive layer at the location of the electrode that extends from the upper surface thereof downward to the electrode to expose the electrode for electrochemical sensing. The conductive trace is provided with a three-dimensional conductive contact portion, formed integrally therewith, that projects through and outwardly of the second non-conductive layer to provide an external pressure interconnection with other electrical elements. As appropriate to the end use of the microsensor desired, a membrane may be applied at the exposed surface of the first non-conductive layer to enclose the well. The membrane may be provided with one or more small holes or pores at well to provide fluid communication with the well to and from the outside, as appropriate to the end use desired.

In this invention microsensor packages are fabricated by a low cost methodology which comprises forming a generally planar conductive trace having an integral three-dimensional contact portion in the form of a projection or button that projects outwardly from the plane of the trace. A sensor is then affixed to the trace at the side opposed to the projection. A non-conductive layer having an opening to accommodate the projection of the trace is laminated to the projection side of the trace and another non-conductive layer having a opening to form a well above the electrode is laminated to the electrode side of the trace.

As another feature of the invention, the microsensors may be manufactured with electrodeposition techniques utilizing an electroconductive mandrel having a pattern of depressions on its surface. A coating of conductive material is first electrodeposited on the mandrel to form a conductive trace for each of a series of sensor package to be produced. The traces will each bear integrally formed projections at the depression sites. An electrode is then formed on each conductive trace. A non-conductive substrate having holes which are appropriately spaced to register with the respective electrodes is then laminated to conductive traces. This structure is then removed from the mandrel and a second non-conductive substrate having holes which register with projections on the traces is then laminated to the trace side of the structure.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be better understood by reference to the figures of the drawings wherein like numbers denote like parts throughout and wherein:

FIG. 1 illustrates, in a side sectional view, a mandrel employed for preparation of a microsensor package of this invention;

FIG. 2 is the same view as in FIG. 1 after deposition of a resist on the mandrel surface and development thereof to expose a microsensor pad forming area;

FIG. 3 is the same view as in FIG. 2 after electrodeposition of a conductive layer on the mandrel for the sensor package;

FIG 4 is the same view as in FIG. 3 after an electrode has been formed on the upper surface of the conductive layer;

FIG. 5 is the same view as in FIG. 4 after lamination of a non-conductive layer onto the conductive layer;

FIG. 6 illustrates, in a side sectional view, the microsensor package construct of FIG. 5 after it has been removed from the mandrel;

FIG. 7 is the same as in FIG.6 after lamination of a second non-conductive layer onto the microsensor package construct;

FIG. 8 illustrates, in a side sectional view, a conductive copper sheet and a non-conductive sheet which are to be laminated together;

FIG. 9 is the same view as FIG. 8 after lamination of the sheet and showing, in side sectional view, an embossing tool to be applied to the laminate.

FIG. 10 is the same view as FIG. 9 after the laminate has been embossed to create a projecting contact and the laminate has been coated with a resist;

FIG. 11 is the same view as FIG. 10 after an electrode has been deposited on the laminate and the resist removed;

FIG. 12 is the same view as FIG.11 after lamination of a non-conductive coverlay onto the laminate;

FIG. 13 is the same view as in FIG. 12 after treatment of the electrode surface in the well to create a silver chloride layer;

FIG. 14 is the same view as in FIG. 13 after deposition of electrolyte medium in the well and depositing of a membrane on the upper surface of the microprocessor package over the well.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The following description illustrates the manner in which the principles of the invention are applied but is not to be construed as limiting the scope of the invention.

The present invention provides for structures or "packages" for electrochemical sensors which will give them improved connectability and reliability. In accordance with this invention these packages may be produced at low cost by batch, modular-manufacturing methodology. With this methodology of this identical miniaturized fluidic devices may be fabricated on a single large sheet with a yield substantially increased over conventional substrates. The individual devices may then be separated and used individually or placed in arrays, such as to produce multiple analyte sensor arrays, using pick and place technology.

The sensor packages of this invention have a non-conductive matrix in which is provided a sensor well for containing sensing chemicals and a sensing electrode at the bottom of the well. A conductive trace is located in the matrix that extends to the electrode to make electrical contact therewith. The conductive trace may be provided with a integral three-dimensional element that projects to the outside of the matrix where it is available to make interconnection with other electrical elements in order to transmit signals from the sensor thereto.

The microsensor packages of this invention may be manufactured in many ways. The various individual steps in the fabrication of the sensor packages of this invention, *per se*, are well known in the art. These may include photolithography, use of photomasks and silk screening and other printing techniques, lamination of films or resists to substrates. and design of specific sensors for specific applications, Literature available on these subjects include the text *Fundamentals of Microfabrication*, M. Madou, CRC Press, Boca Raton, 1997, the disclosures of which are incorporated herein by reference.

There are various methods of fabricating the microsensor packages of this invention. FIGS 1 through 7 illustrate a highly advantageous method for the

fabrication of a typical microsensor package of this invention utilizing electrodeposition on a preformed mandrel to form a series of identical sensor packages at the same time on the mandrel surface.. The mandrel may be prepared as described in U.S. Patent No. 5,197,184 to Crumly et al. A stainless steel mandrel 1 is prepared with pre-drilled dimples or depressions 2 corresponding to the locations for projecting contacts for the individual sensor packages as shown in FIG. 1 for a area of the mandrel for forming one of the sensor pads. Photoresist is applied to the mandrel, and openings created therein corresponding to the sensor pads by photolithographically developing the photoresist to leave an uncovered area in the resist 4. as seen in FIG. 2. Copper is then electrolytically deposited into the openings 4 in the photoresist to form a conductive trace in the form of a pad 5 and the raised contact or projection 6 integral therewith simultaneously as shown in FIG. 3. The trace or pad 5 is typically desired in the form of a foil or sheet for ease in forming an electrode thereon and for supporting same, as will be described. Desirably, pad 5 will extend co-extensively

The photoresist is stripped and then sensing electrode 7 is created on conductive layer or pad 5 as shown in FIG. 4 as by silkscreening silver epoxy ink, such as DuPont type 5504, onto the surface of copper layer 5. Desirably, the bottom side of electrode 7 and the upper side of pad 5 are coextensive in order to better support the electrode and provide good electric contact. Silver is important for use as electrode because it is compatible with an entire class of sensing chemistries that are readily available However, other electrode materials may be employed, for example, gold, paladium, nickel, platinum, iridium, their oxides and combination thereof, as appropriate for the particular microsensors to be constructed from the microsensor packages.

A coverlay of non-conductive material, such as Kapton film, which has been predrilled with holes corresponding to the locations for the sensor wells (over the electrodes) and coated on the underside with adhesive, such as Pyralux adhesive, is laminated onto the exposed surface of conductive layer 10 and electrode 17 to form non-conductive layer 8 as shown in FIG 5. The well holes in non-conductive layer 8 are configured and placed so that layer 8 completely captures the edges of electrode

7 when it is laminated in place. This prevents any leakage of the sensing current around the electrode. The microsensor package construct is now removed from the mandrel, exposing conductive layer or pad 5 and projection 6 as seen in FIG.6. Referring to FIG.7, Kapton film or other non-conductive sheet material which has been predrilled with holes corresponding to the locations of projections 6 and coated with adhesive may be laminated onto the raised contact side of the package to create the second non-conductive layer, if desired, and thereby complete the microsensor package.

FIGURES 8 through 12 illustrate another method for fabricating microsensor packages of this invention. Referring to FIG. 8, a copper foil or sheet is employed to form the conductive layer or trace 10 and a non-conductive sheet, such as of Kapton, is employed as non-conductive layer 11. Sheet 11 has been predrilled to form a opening 12. Sheets 10 and 11 are laminated together, utilizing Pyralux adhesive or the like as shown in FIG. 9. An embossing tool 13 with a conical point is applied against the upper side of layer 10 at the site of opening 12 in layer 11 to form a dimple in conductive layer 10 that protrudes through hole 12 as shown in FIG. 10.

Photoresist 16 is then applied to the exposed upper surface of conductive layer 10. The resist is photo-exposed with the pattern for an electrode to be deposited on the surface and then the resist is developed to expose the area on the surface for etching and then depositing of the electrode. The surface is then etched and an electrode 17 formed on the surface, as by deposition of a silver epoxy ink, such as DuPont type 5504, as shown in FIG 11. A coverlay of non-conductive material, such as Kapton film, which has been predrilled with holes corresponding to the locations for the sensor wells (over the electrodes) and coated on the underside with adhesive, such as Pyralux adhesive, is laminated onto the exposed surface of conductive layer 10 and electrode 17 to form non-conductive layer 18, as shown in FIG. 12.

Other conductive metals may be employed for forming or overplating the conductive trace 5 and contact 6, as for example silver, gold, paladium and nickel. It may advantageous in some cases to use a metal such as silver which can serve as both the conductive layer and the electrode at the well location, thus obviating the need to fabricate a separate electrode at the well.

In the embodiments shown, the raised contact buttons or projections of the conductive layer are offset from the well, in the plane of the non-conductive layers, rather than extending to and below the sensor package directly below the well. This may be desirable for ease of fabrication and to minimize the possibility for damage to the sensor if pressure for securing an electrical contact below the sensor is applied directly over the well. However, in an alternate design of sensor package, the raised contact button may be placed immediately below the well in order to further miniaturize the sensor.

It will be understood that utilizing the foregoing procedure a multiplicity of identical structures may be fabricated at the same time across the surface of the laminate formed as shown in the preceding examples

Microsensors of this invention may then be produced from the microsensor packages by appropriate adaptation of the well of the microsensor package for the desired purpose for the microsensor. This may include the formation of an appropriate oxide or other layer over the electrode, introduction of an electrolyte or other sensing chemicals into the well. It also may include the application of a permeable membrane over the top of the well so as to retain the contents of the well while permitting communication thereto of gases or liquids for analysis.

For a microprocessor package with a silver electrode, the surface of the silver electrode may be converted to silver chloride to produce a sensor sensitive to chloride. Other various sensing chemistries may require different surface finishes on the electrode to react properly (or not react in the case of an inert surface). For instance some enzyme chemistries (and other biological assays) would work best if the electrode or the surface thereof in the well is coated with gold or platinum. Other electrochemical systems may be developed from time to time, which would require a different surface material at the bottom of the well. This will not change the basic microprocessor package.

Starting with the microsensor package described above, and particularly the package depicted in FIG. 12, a microsensor for detecting the chloride ion can be fabricated as shown in FIGS. 13 and 14. The exposed surface of silver electrode 17 in well 19 is chloridized with $FeCl_3$ solution to form the silver chloride layer 20 as seen

in FIG. 13. Well 19 is then filled with an electrolytic medium 21 as seen in FIG. 14. The electrolytic medium can be a liquid but more preferably is in the nature of a hydrogel or a solid polymer electrolyte.

After well 19 has been charged with electrolyte medium 21, a membrane 22 is deposited over the top of well 19 to complete the microprocessor as seen in FIG. 14. Membrane 23 may be a microporous membrane or otherwise contains suitable openings for fluid communication into the well 19 as suitable for the particular sensor. A non-porous plasticized polymeric membrane is normally used for covering potentiometric elements. Ion-selective membranes may be employed, as appropriate for particular sensors.

Sensor packages have been built with the construction shown in FIG. 7. When converted to a chloride sensor by converting the silver surface to silver chloride as shown above, they have a calibration curve typical of similar chloride sensors available in the industry, displaying a typical slope of -0.053 millivolts per decade. Also, a sensor for potassium has been built with the package construction shown in FIG. 7. The calibration curve for the potassium sensor displayed a slope of 59 millivolts per decade.

In similar fashion microprocessors may be fashioned from the microprocessor packages for sensing other ions using chemistries well known in the industry. For example, if the hydrogel layer contains an electrolyte solution which has constant concentration of chloride ion, and the membrane contains the appropriate ionophore for potassium ion, an electrochemical potential will be created across the membrane between the sensor and the unknown sample that will depend on the concentration of potassium ions in the unknown. This dependence is described by the Nernst equation. Such hydrogels are available, such as PHEMA, which can be prepared by dissolving hydroxyethyl methacrylate (97%, Aldrich), polyvinylpyrrolidone (Aldrich) and 2,2-dimethoxy-2-phenyl-acetophenne (99%, Aldrich) as photoinitiator in ethylene glycol (99+%, Aldrich). An appropriate ion specific membrane, for instance, can be created by dissolving PVC (Aldrich), potassium tetrakis(4-chlorophenyl)borate (Fluka), (+)-bis(2-ethylthexyl)sebacate (94%, Aldrich), and (+)-valinomycin (90%, Aldrich) as ionophore in a suitable solvent such as Tetrahydrofuran (99.9%, Aldrich)

and applying a few drops to the top of the hydrogel, allowing the membrane to dry between applications.

In use the microsensors of this invention may be placed adjacent an external electrical contact, such as in substrate 23 shown in FIG. 14, with the projecting contact 6 pressed thereagainst to provide a stable and secure electrical connection with external circuitry.

Although the description above contains many specificities, these should not be construed as limiting the scope of the invention but as merely providing illustrations of some of the presently preferred embodiments of this invention. Various other embodiments and ramifications are possible within it's scope.